



LAWRENCE  
LIVERMORE  
NATIONAL  
LABORATORY

# Review of Reactivity Experiments for Lithium Ternary Alloys

A. Jolodosky, A. Bolind, M. Fratoni

September 28, 2015

## **Disclaimer**

---

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

## **Review of Reactivity Experiments for Lithium Ternary Alloys**

Alejandra Jolodosky, Alan Bolind, and Massimiliano Fratoni  
University of California, Berkeley  
FY2015 Report

### **1. Introduction**

Lithium is often the preferred choice as breeder and coolant in fusion blankets as it offers high tritium breeding, excellent heat transfer and corrosion properties, and most importantly, it has very high tritium solubility and results in very low levels of tritium permeation throughout the facility infrastructure [1]. However, lithium metal vigorously reacts with air and water and exacerbates plant safety concerns [2]. Consequently, Lawrence Livermore National Laboratory (LLNL) is attempting to develop a lithium-based alloy—most likely a ternary alloy—which maintains the beneficial properties of lithium (e.g. high tritium breeding and solubility) while reducing overall flammability concerns for use in the blanket of an inertial fusion energy (IFE) power plant [3-4]. The LLNL concept employs inertial confinement fusion (ICF) through the use of lasers aimed at an indirect-driven target composed of deuterium-tritium fuel. The fusion driver/target design implements the same physics currently experimented at the National Ignition Facility (NIF). The plant uses lithium in both the primary coolant and blanket; therefore, lithium-related hazards are of primary concern. Reducing chemical reactivity is the primary motivation for the development of new lithium alloys, and it is therefore important to come up with proper ways to conduct experiments that can physically study this phenomenon. This paper will start to explore this area by outlining relevant past experiments conducted with lithium/air reactions and lithium/water reactions. Looking at what was done in the past will then give us a general idea of how we can setup our own experiments to test a variety of lithium alloys.

### **2. Lithium Reactions with Air**

High energy reactions of lithium with air can occur during an accident. Such accidents involve a rupture or leak in plant components, which results in the release of lithium into the containment atmosphere. The following sections outline past experiments conducted with lithium or with lithium-lead when reacting with air.

#### **2.1. Hanford Engineering Development Laboratory (HEDL) Experiments**

HEDL conducted tests in the late seventies and early eighties to examine the effects of lithium reactions with a multitude of materials [5-6]. Those of interest here are nitrogen, dry air and moist air. Tests were conducted in which 10 kg pounds of lithium at a chosen temperature were transported to a preheated reaction pan with an exposed surface area. The reaction pan was enclosed by a carbon steel containment vessel with a controlled atmosphere. Figure 1 shows the geometry of the facility. Results from experiments in which lithium was exposed to a limited amount of normal humidity air showed that the original lithium pool temperature does not have an effect on the maximum pool and flame temperatures reached in the reaction. Two of the experiments showed that half of the lithium reacted with nitrogen while the other half reacted with oxygen. The maximum pool temperature in these cases was 1000°C. The largest aerosol product formed from these reactions was  $\text{Li}_2\text{O}$ . A much larger scale experiment with a total of 45.4 kg of lithium and unlimited amount of air produced different results, yielding 94% of lithium oxide and 29.4% of lithium carbonate aerosol. Aerosols were created when lithium would randomly ignite and burn in normal humidity air. Lithium carbonate aerosol was more stable than lithium oxide or hydroxide. Additionally, at high temperatures when there is enough oxygen available to react, lithium-oxygen reactions overrode lithium nitrogen reactions. Experiments were also performed with moist air, showing a more rapid oxidation of lithium, igniting and burning with a yellow-red flame. Lithium interactions with moist air added an additional component from the lithium-water vapor interaction producing lithium hydroxide.

In addition to only experimenting with air, lithium was combined with isolated components of air to examine its reaction. Lithium-oxygen reactions showed the formation of an oxide film. When lithium was combined with nitrogen, a buildup of nitride was observed, which reduced the reaction rate. Additionally, the heat of reaction was lower than that in air and therefore the reaction was less vigorous than that of lithium with air. When lithium reacted with carbon dioxide at a low temperature, below 300°C, only a surface reaction was observed. However, at high lithium temperatures, above 500°C, lithium reached temperatures higher than its melting point and was ignited and produced a flame of about 1400°C.

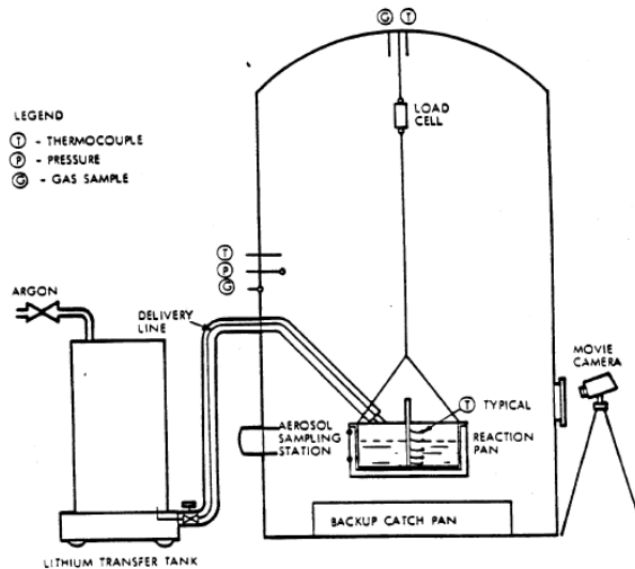


Figure 1. Geometry of HEDL lithium-atmosphere reaction experiments.

HEDL conducted tests with lithium-lead and air. These tests were performed to model reactor accident scenarios. Lithium-lead alloy pool reaction tests with air were performed to predict accidents where the lithium alloy leaks from the blanket to form a pool that will be exposed to an atmosphere of air, nitrogen, or carbon dioxide. Lithium-lead reacted the least with nitrogen; it did not form any aerosols or combustible gas and produced only a slight amount of heat. The alloy had similar results when reacting with air when the initial temperature of the pool was of 450°C. However, with a pool temperature of 750°C, lithium and lead aerosols were released. The reaction with limited quantities of carbon dioxide was exothermic at an initial alloy temperature of 450°C. It is assumed that aerosols would have formed if a larger amount of carbon dioxide was used.

## 2.2. MIT Liquid Lithium Reactions with Oxygen-Nitrogen Mixtures

The first experiments conducted at MIT were performed in 1984 to study lithium-nitrogen reactions [7]. A diagram of the experimental set-up is shown in Figure 2. Purified nitrogen flowed constantly from a tank (tank 1) on to a preheated reaction site and preheated. At the reaction site, the gas reacted with pure liquid lithium at specified temperature. The generated aerosols passed through the heat exchanger and the filter and were stored in a separate tank (tank 2). Pressure gauges on tanks 1 and 2 recorded the respective losses and gains of pressure. Thermocouples recorded gas temperatures; from this, the ideal gas law was used to calculate losses and gains (in moles). The difference between the amount of gas accumulated in tank 2 and the amount lost from tank 1 equals the amount of gas lost to the lithium-nitrogen reaction. This information plus the time from the internal clock in the data acquisition system allowed the reaction rate to be calculated. There were at least five types of uncertainties in this experiment, and they were accounted for in the results. The first was related to the accumulation of a nitride layer, which slowed the reaction rate. This, however, is a common part of the lithium-nitrogen reaction. Secondly, uncertainties were observed due to the increase of the lithium pool surface area caused by the spreading of molten lithium along the walls of the container due to the high surface tension of lithium, and by a non-flat surface of lithium during the reaction. As a result, the reaction rate increased. The third uncertainty was from the impurities found in both nitrogen and lithium. Additionally, there were human errors stemming from readings, recordings, and measurement. Other uncertainties accounted for was due to insufficient gas flow at high temperatures causing reaction rates to depend on the amount of gas flow. In addition, the lithium pool temperature experienced drastic changes at high temperatures caused by vigorous reactions, and therefore caused uncertainties in measurements.

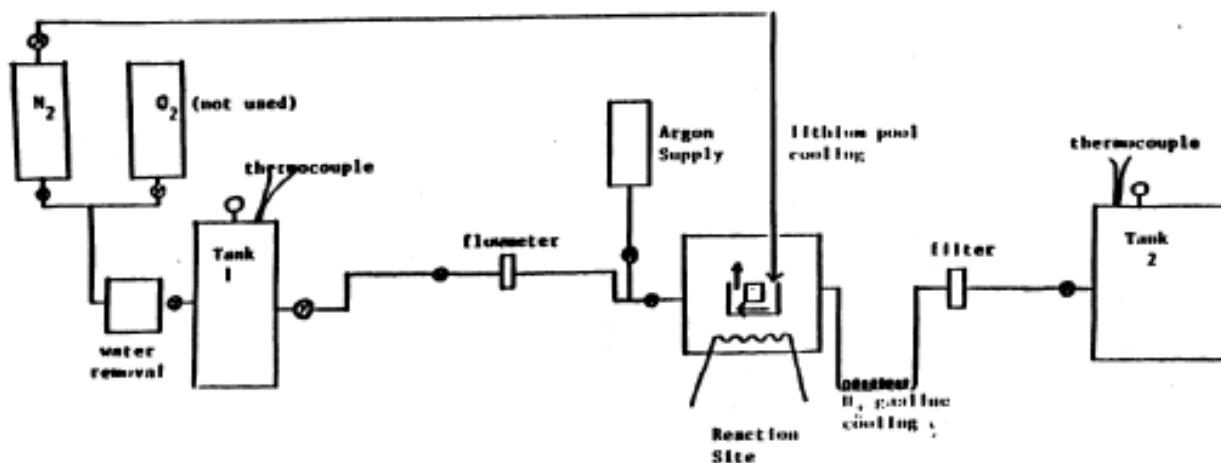


Figure 2. Experimental set-up for MIT 1984 lithium-nitrogen experiments.

In 1986, experiments at MIT were done to examine the kinetics of lithium-nitrogen and oxygen reactions. This would depict how lithium reacts with air under a non-humid environment. It was decided to conduct the experiments under dry conditions first to understand the kinetics of lithium with mixed nitrogen and oxygen. Afterwards, water vapor could be added, and its role as a catalyst of the reaction rate could be obtained. Experiments using the nitrogen and oxygen mixtures were conducted at temperatures ranging from 350°C to 1100°C, while the pure nitrogen experiments were done at a range of 450°C to 700°C. The flow was kept constant with a rate of 2.0 to 3.5 liters per minute. Some of the experiments over 900°C needed higher flow rates of 5.5 liters per minute to gather measurements that were independent of gas flow. The area of the lithium pool surface was only 3.88 cm<sup>2</sup> in order to prevent a large release of energy in the case of an accidental fire. Pressures and temperatures were monitored every 3 seconds. This experiment was found to be one of the most thorough regarding lithium/air type reactions and thus will be discussed in detail in the following sub-sections.

### 2.2.1. Experimental Process

A diagram of the setup is illustrated in Figure 3. Tanks 1 and 2 were filled with nitrogen and argon, respectively, and released to the atmosphere several times in order to purge out impure gases and have the purity of each gas reach 99.9 percent or higher. The oxygen fractions that were bled into tank 1 to combine with nitrogen varied from 5 to 20 percent. Oxygen was not bled into tank 1 right away to avoid a decrease in pressure from unavoidable leaks, rather it was done during the time the lithium in the reaction chamber was heated to a desirable temperature. The lithium was held in a stainless steel container. Above the container there was a cap; a nickel o-ring was inserted in the gap between the container and cap. The container where pure lithium, after inspected, was inserted contained pure argon gas. Although as many impurities as possible were extracted from the lithium, some still remained. Impurities were problematic in experiments performed in the low temperature range ( $\leq 500^\circ\text{C}$ ) because they increased the melting temperature of the lithium. To ensure all the lithium was melted, it was heated up to about 600°C first, and then brought down to the desired temperature. Nevertheless, it was predicted that these impurities could affect the consistency of the reaction rate. This was not a problem in the high temperature cases since the impurities would most likely have sunk to the bottom of the container.

To conduct the experiment, valves were opened so the gas could flow from tank 1, through the reaction chamber, to the second tank. The gas flow to the second tank was stopped at the time in which the gas composition after the reaction took place could be measured. By knowing the final gas composition, one could decipher the amount of oxygen and nitrogen that reacted with the lithium in the container.

During the experiment some inaccuracies were observed and accounted for. The first and largest occurred at lower temperatures due to impurities found in the lithium. These impurities increased the lithium melting temperature from 185°C to about 400°C. The second inaccuracy encountered was the spreading of the reaction products along the walls of the container, increasing the reaction rates. Surface irregularities observed in the temperature range from 400 to 700°C also increased the reaction rates up to 20%. Additionally, a third error was observed regarding the accuracy of the oxygen composition; the maximum difference in the oxygen fraction of the mixed gas was about

20%. This occurred in the cases with the least amount of oxygen. To maintain the assumption that the same fraction of nitrogen and oxygen was consumed for a reaction after the data points were collected, a valve located in front of tank 2 was closed to store only the gas that had just passed through the container. This prevented any form of error that might have arisen if the valve was not closed. The fourth major source of error that occurred in low temperature cases was the formation of a lithium nitride layer which considerably lowered the reaction rates. A lithium oxide layer was also formed but unlike lithium nitride, it could easily be scraped off. Only a few data points could be obtained in such cases since the reaction product prevented additional reactions. The fifth source of error was related to the gas-flow dependency of the reaction rates with oxygen at temperatures above 900°C. One solution was to increase the flow rate of the gas mixture from 3.5 liters/min to 5.5 liters/min. Nevertheless, when temperatures were high, enough oxygen would react with lithium that the rates were gas-flow dependent. Error propagation was performed on some of these errors (oxygen composition, surface area enlargement, and surface irregularities) and calculated to be 28%.

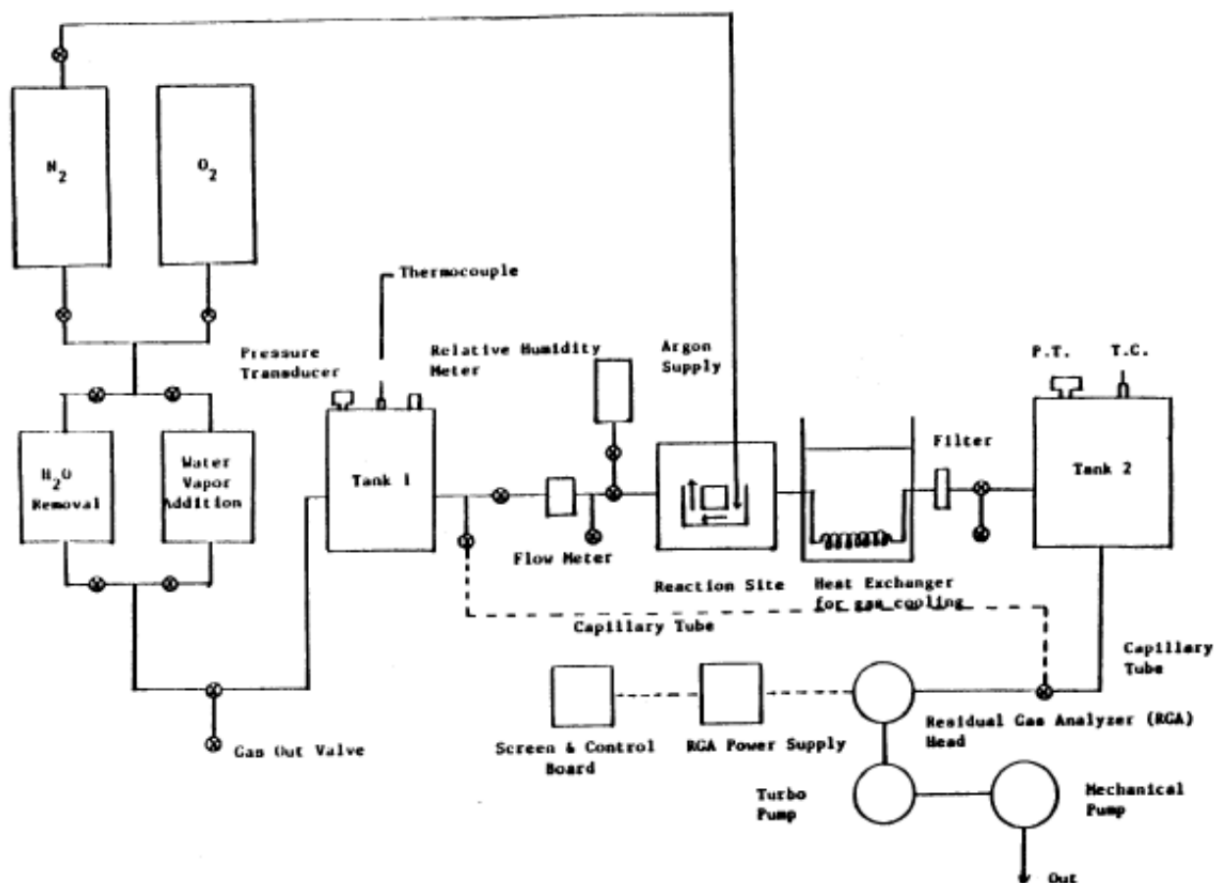


Figure 3. MIT 1986 lithium-nitrogen/oxygen experimental setup.

### 2.2.2. Experimental Results and Analysis

The first measurement was conducted after the full flow rate was established to prevent measuring temperatures from the lithium flame or from radiative heat generation during the reaction process. Results for nitrogen reactions agreed with the previous 1984 experiment. All the lithium in the lithium-oxygen reaction was consumed. Part of the container melted due to the temperature of the lithium flame which was probably higher than the 316 stainless steel melting temperature (1300°C). The environment in this type of reaction was very corrosive.

For the lithium-mixed gas experiments three compositions were used: 1) 80% N<sub>2</sub>, 20% O<sub>2</sub>; 2) 90% N<sub>2</sub>, 10% O<sub>2</sub>; 3) 95% N<sub>2</sub>, 5% O<sub>2</sub>. The reasoning behind utilizing multiple concentrations was to observe how the reaction rate

changes as the fraction of oxygen in the mixed gas decreases. To obtain the reaction rates, first, the decrease in nitrogen and oxygen pressures in tank 2 from the reactions was calculated. Once those pressures were known the ideal gas law could be employed to calculate the number of moles of  $N_2$  and  $O_2$  consumed, which were divided by the time of the reaction to obtain the reaction rate. Lithium nitride was formed in the surface of the pool with lithium oxide on top. Lithium oxide was a white, powder-like substance which could easily be scraped off. At high temperatures, lithium oxide is more likely to be formed as aerosols.

Results show that the lithium-nitrogen reaction rates decreased due to the presence of oxygen. One parameter studied in the analysis was the nitrogen inhibition factor, defined as the ratio of the lithium-nitrogen reaction rate with the presence of oxygen to the lithium-nitrogen reaction rate without oxygen presence. The inhibition factor was dependent on both oxygen concentration and lithium pool temperature. Within temperatures of 800 and 1000°C the inhibition factor increased which means that lithium-nitrogen reactions were strong enough that nitrogen was competing with oxygen to react with lithium. Contrarily to lithium-nitrogen reactions, lithium oxygen reactions were gas-flow dependent; most of the oxygen was consumed by the reaction at high temperatures, and the reaction rate would reach a finite value that corresponded to the concentration of oxygen in the mixture. It was also discovered that lithium oxygen reactions are dependent on the temperature of the lithium pool.

As previously discussed, lithium nitride and oxide were the two major reaction products. At temperatures lower than 800°C, lithium nitride formed at the pool surface, and lithium oxide formed on top of it. At higher temperatures, most of the layer was lithium nitride since lithium oxide formed aerosols. The behavior of the reaction is mostly dominated by the parabolic law that is found when the rate controlling the reaction is diffusion of one of the reactants through a surface film, which in this case is identified as the reaction product layer. Additionally, the results showed cracks forming during the reaction. More cracks formed at higher oxygen concentrations and higher lithium pool temperatures. Cracks increased the reaction rate, and therefore offset the reduction of the reaction rate from the formation of the nitride layer. It was concluded that the reaction rate at lithium pool temperatures lower than 800°C were controlled by the thickness of the nitride layer, while at high temperatures three factors controlled the reaction rate: 1) thickness of nitride layer; 2) concentration of oxygen; and 3) cracks on the surface of the pool.

### **3. Lithium Reactions with Water**

For reactions with water, the past experiments involving reactions of lithium-lead will be examined as opposed to the reactions of pure lithium. This is because lithium alone is less dense than water unlike the alloys that will be used in future experiments and lithium-lead. Therefore, the setup of lithium-lead experiments will more likely resemble the type of experiments we want to perform. Past studies investigated reactions of lithium-lead with both water and vapor. Five possible contact modes of lithium with water were determined: 1. Pressurized injection of water into the lithium, 2. Pouring the lithium alloy into water, 3. Pouring the water into the lithium alloy so it is layered on top, 4. A lithium alloy pool surrounded by a steam environment, 5. Lithium alloy spray into a steam environment [2].

#### **3.1. Small Scale Experiments**

Small scale experiments were run for LiPb and water interactions to determine the rate of hydrogen production. If the hydrogen production rate is known, proper dynamic mixing models can be used to estimate the amount of hydrogen produced during accident conditions. Experiments included dropping droplets of the alloy into water and vice versa, injecting the alloy into water, or even passing steam over the alloy. A few conclusions were derived from these experiments: 1. The amount of hydrogen produced is loosely dependent on temperature but largely dependent on the contact area between the metal and water. 2. The contact area is dependent on the amount of force used to bring the water and alloy together. 3. If the species react chemically, it prevents an explosive pressure rise. 4. The hydrogen reaction rate of lithium/water reactions is higher than that of lithium-lead/water reactions [8]

## 3.2. Large Scale Experiments

### 3.2.1. BLAST Experiments

Large scale experiments are able to properly simulate the contact modes previously described. One accident case that was found to be investigated was a steam-generator-tube rupture. Contact of water and steam with LiPb can create both a chemical and thermal reaction. The BLANKet Safety Test (BLAST) simulated a large break by injecting subcooled-to-saturated water, at a maximum pressure of 10 MPa, into a stagnant pool of 470 kg of LiPb [2]. The tests were conducted to examine how the pressure changes when a significant amount of lithium-lead reacts with water at different injection temperatures. The main parts of the experimental model are the reaction vessel with the injector, the expansion tube, and the expansion vessel. A diagram of the setup is given in Figure 4. The maximum amount of water that can be injected is 5 kg with a maximum temperature of 300°C at 10 MPa. The pressure history in the reaction and expansion vessel were recorded along with the pressure and temperature in the injection, expansion and safety vessel.

The results from this experiments show an increase in pressure in the reaction vessel with a peak at the beginning. After depressurization, the pressure rises again. In the experiment, BLAST 4, where the rupture disk did not fail, once the reaction vessel reached the injection pressure, water injection automatically stopped. This is due to the lack of pressure difference between the injector and reaction vessel. It is interesting to note that for the expansion vessel, the gradient is the same as the reaction vessel after 500 ms. The reason for this was divided into three phases: 1. At  $t < 1$  ms, pressurization of the injected water is mainly due to system compressibility and reaction vessel geometry. 2. At  $t < 250$  ms, a pressure increase in the reaction vessel forces the reaction products into the expansion tube. Water vaporization, hydrogen production, and geometries of the reaction and expansion vessels affect the pressure. 3. At  $t > 250$  ms hydrogen production dominates the pressurization in the system which affects the reactor vessel, expansion tube, and expansion vessel. It was concluded that the injection pressure limits the pressure in the reaction area.

Later experiments of this nature were conducted including radioactive species to examine which and how much radioactive materials were released. About 0.5-0.55 moles of hydrogen were released per mole of water injected. Solid aerosols included potassium, bismuth, lithium thallium, tellurium, and lead. Mercury gas was also released.

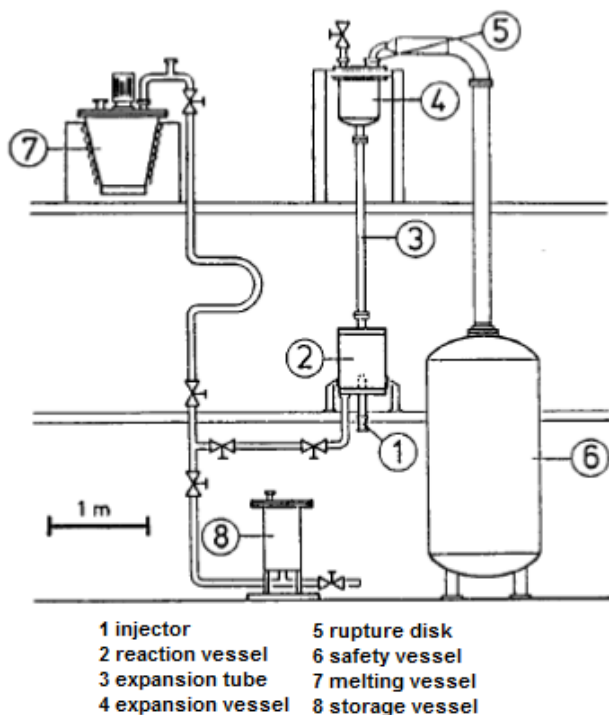


Figure 4. BLAST experimental facility.



### 3.2.2. Hanford Engineering Development Laboratory Experiments

HEDL large scale experiments consisted of injecting steam at 7 g/s into an insulated reaction container with a 200 kg pool of 500°C lithium-lead for 325 seconds [8]. The experimental facility is outlined in Figure 5. A reaction vessel was placed within a vessel containing an argon atmosphere. A condenser, attached the reaction chamber, condensed steam to allow the release of hydrogen to the containment atmosphere where it was measured with a hydrogen monitor. Five thermocouples measured the temperature of the lithium-lead pool. After 240 seconds into the experiment, the lithium-lead pool reached its maximum temperature of 870°C. All of the steam reacted with lithium. First, steam reacted with lithium to form  $\text{Li}_2\text{O}$  along with hydrogen. After lithium started to be depleted, the steam reacted with  $\text{Li}_2\text{O}$  to form  $\text{LiOH}$ . Consequently,  $\text{LiOH}$  reacted with lithium to form additional hydrogen. Reaction products were found on top of the pool. It was also concluded that both lithium and water were mixed completely in the reaction chamber since both completely reacted with one another. Chemical analysis of the reaction products showed that only 0.37% of the total amount of lithium remained by the end of the experiment. Moreover, the amount of hydrogen released was measured as 0.56 mole per mole of lithium that reacted.

A similar experiment was conducted with pure lithium and steam. In this case, 320°C steam was injected at 2.6 g/s into a reaction vessel for 510 seconds. The reaction vessel contained 10 kg of lithium at 580°C. Similar to the previous experiments, both components were well mixed throughout the experiment. The main reaction products in this case were  $\text{Li}_2\text{O}$  and  $\text{LiH}$ . It was found in this case that the rate of heat production was three times greater than of the lithium-lead/water reaction.

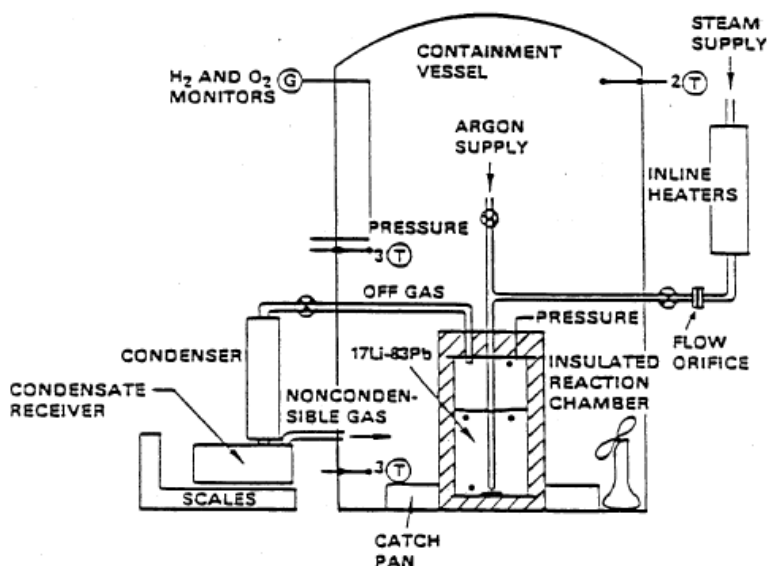


Figure 5. HEDL lithium-lead/steam experiments facility.

### 3.2.3. University of Wisconsin Experiments

The experiments performed by the University of Wisconsin (UW) consisted of pouring water into a lithium-lead pool. This case is most likely linked to an accident scenario where water comes into contact with lithium, forming of stratified layers with different densities [8]. These small scale experiments were run to determine the rate of hydrogen production. The setup consisted of a stainless-steel cylindrical vertical column containing the reactant and products, shown in Figure 6. The lower portion was where the liquid metal, about 20-65 g, was inserted through a drilled cavity. On top of the liquid metal pool was a butterfly valve which kept the liquid metal and water, above the valve, separated. The amount of water held above the valve was around 1 liter. After the metal and water were heated to the desired temperatures, the valve was opened to let the water pour into the liquid metal pool. A closed volume was purposely designed to collect and measure the amount of hydrogen. The size of the liquid cavity was designed such that the contact area between metal and water was kept relatively constant through the experiment. The liquid metal was heated by two semi-cylindrical electrical heating units that formed an annulus around the lower portion of experimental apparatus. The metal temperature ranged from 350 to 650°C. The temperature of the water

ranged from 60 to 90°C and was controlled by a water cooling circuit. The cooling circuit contained a temperature controller that exhibited both heating and refrigeration units. This arrangement allowed the water to be heated to the desired temperature before the experiment was actually performed. A temperature control loop was also in the upper region of the apparatus to remove heat formed during the reaction. To ensure that the contact area between the two components was made up of liquid metal and water vapor, the initial temperature of the water was chosen such that film boiling (i.e., a thin layer of steam and hydrogen covered the liquid-metal surface) occurred at the surface of the alloy. The experiment was performed under an argon atmosphere. Argon was also used with a pressure equalization line to remove the pressure difference between the water and liquid metal sections before they were combined while they were in the process of heating up. This pressure equalization line would allow argon to flow from the gas region on top of the liquid metal pool to the gas region above the water column, and out of the system. A pressure transducer and three thermocouples measured the two variables of the experiment. One thermocouple was located at the bottom of the apparatus to measure the temperature of the liquid metal. The other two were placed in wells connected to the top portion where the water was, to measure the bulk water temperature and the temperature of the gas above the water. Once the experiment was conducted and the bulk water temperature, the gas layer temperature, and the system pressure were recorded, a computer program analyzed these data and solved for the pressure and mass of hydrogen generated from the reaction. Since the gas from the reaction was composed of a mixture of argon and hydrogen, by knowing the argon mass, the program was able to derive the hydrogen mass. Details on how this was done are explained in the paper.

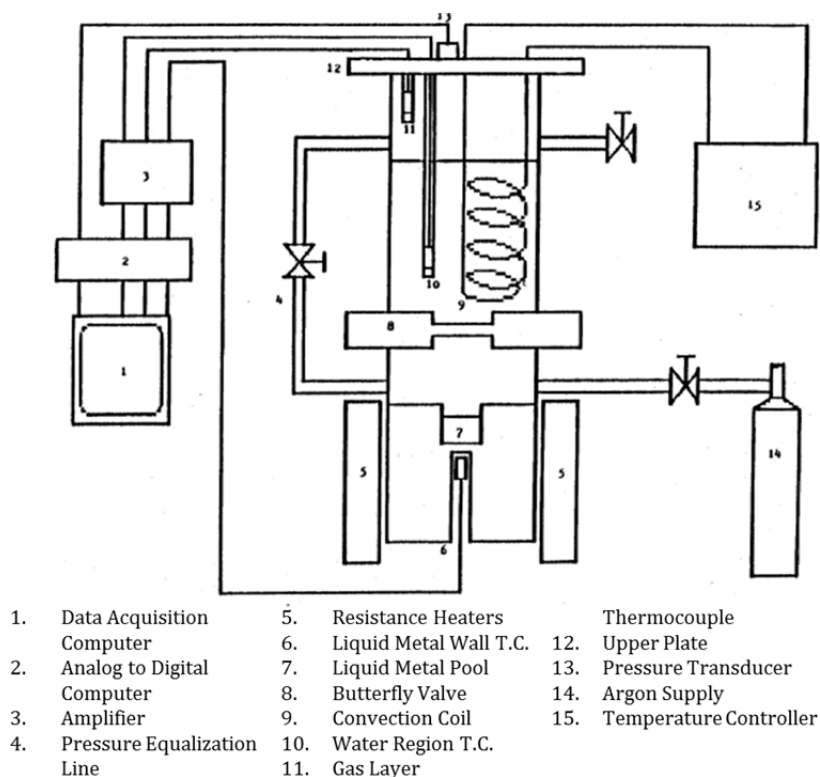


Figure 6. University of Wisconsin lithium-lead/water tests facility.

At the beginning of the experiment, the combination of unequal boiling and condensation rates, and the delay of the gas thermocouple made it exceedingly difficult to accurately measure the partial pressure of hydrogen. Measurements were much more precise after thermodynamic liquid-vapor equilibrium was reached, which occurred after 100-150 seconds. Therefore, the results of this experiment were only accounted for after 200 seconds. Hydrogen pressure corrections were made on the results due to additional deficiencies in the gas thermocouple.

Results concluded that the extent of the reaction between the metal and water was not dependent on initial water temperature. What affected the rate of hydrogen production was the diffusion in the metal sample and the

temperature of the liquid metal. Using the data from the experiment, a kinetics model was developed to calculate the hydrogen mass produced and subsequently the reaction rate. The model assumed that the reaction was determined by the rate of diffusion of lithium atoms and products such as  $\text{Li}_2\text{O}$  and  $\text{LiOH}$  at the liquid metal surface. More detail on the model is outlined in the paper. From the calculations, it is clear that the amount of hydrogen generated was a function of the initial temperature of the lithium alloy and that the reaction rate was linear. When water first interacted with the lithium, all the lithium atoms at the surface were quickly consumed in the reaction. After this point, the rate of the reaction was dependent on the diffusion of lithium atoms to the surface and of lithium hydroxide away from the surface. This was the linear relationship outlined in the results of this model. Additionally, it was determined that the amount of hydrogen generated in moles was equal to half of the moles of lithium consumed. One thing to note was that only the initial temperatures of the water and liquid metal were accounted for as variables in the experiment; other variables such as the volume of the water and pressure of the system could be changed and evaluated to see if they affect the reaction rate. If this type of experiment were to be replicated, changes should be made to make the results more accurate, such as changing the location of the thermocouples.

#### 4. Experimental Recommendations

The first thing to consider when deciding how to conduct this type of experiment is whether it will be small-scale or large-scale. Past small-scale experiments were instructive, but a lot were done before conducting large-scale ones or to use the data to create computational models. In the same way, we may benefit from conducting simple small-scale experiments in existing, rather than bespoke, calorimeters, such as a Netzsch Adiabatic Reaction Calorimeter (ARC). These data could serve as initial verification of modeled estimates of thermodynamic and simple kinetic data, and the use of commercial, off-the-shelf equipment should allow these experiments to be conducted relatively quickly and inexpensively. Ultimately, though, large-scale experiments seem more appropriate for our purpose, as they would better depict how the alloys would behave in the actual reactor environment. Both air and water reactions should be considered when examining the potential chemical reactions of the lithium alloy. The MIT lithium/nitrogen and oxygen experiments can be used as a model when looking at the reaction of the lithium-alloy with air. One of the advantages of the experimental setup is the option to remove humidity from the gases or add it in to see how it affects the reaction rate. The way the reaction rates are calculated, utilizing two tanks to calculate how much is lost from one and gained from the other, is straightforward. Additionally, the use of an updated data acquisition system will allow the results to be obtained more easily. The study outlined all the uncertainties encountered in the experiment, such as impurities in the lithium and the accumulation of the nitride layer. Before conducting the experiment, we can make an effort to account for all the inaccuracies, but if this is not possible, we can at least be aware of them when taking measurements. The MIT experiment can be used as a guide but essentially we can redesign the setup with different materials, sizes of containers, and placement of thermocouples and pressure transducers to fit our needs and get the most accurate results. The same can be done with lithium alloy/water interactions and some of the past experiments. For experiments involving water reactions, the type of accident scenario must be considered. In our case, the only place where water is found is in the steam generator. Therefore, we would most likely want to perform experiments involving a steam generator tube rupture similar to the BLAST experiments, or the HEDL steam injection experiments. The experimental setup of the BLAST studies is simple and straightforward. Similar to the lithium alloy/gas experiments, the BLAST setup can be used as a template for our own experiments while designing the experimental facility that meets our specific needs. If other types of lithium alloy/water interactions are to be considered, we can look into other past experiments, such as the UW pouring experiments, as a guide.

#### References

1. J. F. Latkowski, et al., "Chamber Design for the Laser Inertial Fusion Energy (LIFE) Engine," *Fusion Sci. Technol.*, **60**, 54-60 (2011).
2. M.L. Corradini, D.W. Jeppson, "Lithium Alloy Chemical Reactivity with Reactor Materials: Current State of Knowledge," *Fusion Engineering and Design* **14.3-4**, 273-88 (1991).
3. E. I. Moses, "The National Ignition Facility and the Promise of Inertial Fusion Energy," *Fusion Sci. Technol.*, **60**, 11-16 (2011).
4. M. Dunne, et al., "Timely Delivery of Laser Inertial Fusion Energy (LIFE)," *Fusion Sci. Technol.*, **60**, 19-27 (2011).

5. D.W. Jeppson, et al., "Interaction of Liquid Lithium with Various Atmospheres, Concretes, and Insulating Materials; and Filtration of Lithium Aerosols," HEDL-TME-79-7 UC 20 (1979).
6. L.D. Muhlestein, D.W. Jepsen, "Liquid Lithium Containment and Control," HEDL-SA-1623 (1978).
7. T.K. Gil, M.S. Kazimi, "The Kinetics of Liquid Lithium Reaction with Oxygen-Nitrogen Mixtures," DE-APO7-791DOO19 (1986).
8. J.P. Herzog, "Lithium-Lead/Water Interactions: Experiments and Analysis," UWFD-791 (1989).